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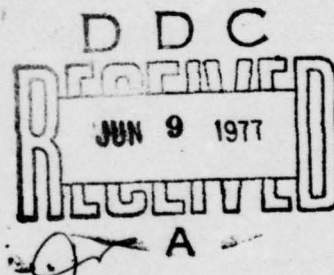
HOT FLAME CUT STUDY

VOLUME III of III

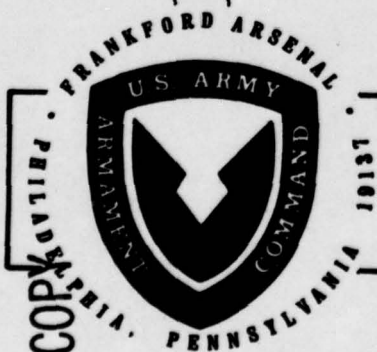
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January 1977



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Manufacturing Technology Directorate

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER FA-TR-77006 - Vol-31	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) HOT FLAME CUT STUDY, VOLUME III OF III.	5. TYPE OF REPORT & PERIOD COVERED Final Engineering Report	
6. PERFORMING ORG. REPORT NUMBER		
7. AUTHOR(s) DUANE O. GUSTAD	8. CONTRACT OR GRANT NUMBER(s) DAAA25-74-C-0624 MODIFICATION: P00002	
9. PERFORMING ORGANIZATION NAME AND ADDRESS FRANKFORD ARSENAL SARFA-MTT-F PHILADELPHIA, PA 19137	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS MM&T PROJECT NO.: 5726358 & 5736358	
11. CONTROLLING OFFICE NAME AND ADDRESS FRANKFORD ARSENAL MANUFACTURING TECHNOLOGY DIRECTORATE PHILADELPHIA, PA. 19137	12. REPORT DATE January 1977	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	13. NUMBER OF PAGES 35	
15. SECURITY CLASS. (of this report) UNCLASSIFIED		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES This project was accomplished as part of the U.S. Army manufacturing technology program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army Materiel.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Hot Shearing Hot Flame Cutting Hot Billet Separation Billet Separation		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The hot shearing and hot flame cutting concepts of billet separation for use in projectile forging applications were investigated during this project. The hot parting concept of billet separation involves heating 20 to 24 foot lengths of billet stock to forging temperature, hot shearing to required mult length afterwhich the hot sheared mult moves directly to the forging press. Using this concept of billet separation,		

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20. ABSTRACT (Cont)

heating to forging temperature, parting to mult length and forging can be accomplished as a completely integrated, synchronized and automatic operation.

Hot shearing studies were conducted on the 105 mm M1 and 155 mm M107 projectiles. Hot shearing was determined to be a completely satisfactory method of billet separation for projectile manufacture. Benefits which can be achieved from use of hot sheared mults are derived from reduced material handling, reduced material waste, reduced operating cost and improved projectile cavity surface finish.

Hot flame cutting was determined to not be a successful process for parting of mults for projectile manufacture. Slag and molten metal caused problems in subsequent forging operation.

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## I. INTRODUCTION

Modification P00002 to the Hot Shear Study Contract DAAA25-74-C-0624, effective 12 June 1975, covers additional work to study the Hot Flame concept of billet separation in conjunction with manufacture of 105MM, M1 projectile bodies. The study involved heating steel to forging temperature and flame cutting the heated steel to mult lengths, followed by normal processing thru the nosing operation. Specifically, the following steps were to be taken:

- A. Set up flame cutting equipment adjacent to the exit end of a billet heating furnace.
- B. Establish by experimentation the parameters of hot flame cutting which provide the best mult end and surface quality.
- C. Hot flame cut 100 mults one inch longer than required for 105MM forgings. Saw to proper length/wt.
- D. Hot forge 50 mults with flame cut end up in the die and 50 mults with flame cut end down.
- E. Inspect by visual and magnetic particle methods after forging and after the nosing operation.
- F. Record all data regarding parameters and inspection results and document in a final report.

This report fulfills the documentation requirement of the Scope Of Work of this contract modification.

## II. EQUIPMENT

### A. HEATER

The heater and indexing/conveying equipment available for this study was the same as used for the Hot Shear Study. The heater is capable of heating full 21 foot billets of  $3\frac{1}{2}$ " R.C.S. stock. The indexing mechanism is of the hitch-feed type which can retract the bar for additional heating as well as advance normally for cutting.

### B. CUTTING MACHINE

The torch tractor used to transport the torch was a Linde Type CM-45 with a maximum speed of 33 inches/minute. Since the billet does not lay flat in the heating equipment but rather lays with the diagonals running vertically and horizontally, the track of the cutting machine had to be set at  $45^{\circ}$  to the horizontal to allow a constant depth of cut. To obtain traction, the friction drive wheels were replaced with spur gears and mating gear racks were mounted on the track. A cable and counterweight were employed to maintain a constant travel speed regardless of direction and to reduce stress on the drive mechanism. (See figures 1 & 2 on pages 25 and 26.)

The on-off reverse switch was removed from the tractor and mounted in a hand-held switch box connected to the tractor by a flexible cord.



Government-furnished equipment was made available as part of the contract package in the form of an Airco #10 Planograph two-torch pantograph-type cutting machine. The need for light-weight, compact portable equipment due to the cutting location and the ready availability in-house of such equipment dictated the NPI choice of the Linde equipment over the GFE.

#### C. TORCH

The torch employed was a Linde Oxweld Type C-58-2, two-hose torch using one piece tips. No provision was made for water cooling of the torch.

Two styles of tips were used, each in several sizes. One type had a straight drilled cutting oxygen orifice, the other had a divergent orifice.

Oxygen and acetylene were supplied to the torch by means of conventional hoses, two-stage regulators and cylinders.

#### D. BILLET STOP

Since the billet heater was located in line with the Hot Shear press, the flame-cutting equipment had to be located in the narrow space between them. An effective fixture to control mult length was obtained by clamping a two-foot piece of billet stock in the Hot Shear Press. One end contacted the adjustable billet stop of the Hot Shear Press and the other end thus became the billet stop for the flame cut setup. (See Fig. 1, page 25)

### III. PROCEDURE

#### A. ESTABLISHMENT OF PARAMETERS

The objective was to establish a set of operating parameters yielding maximum economy that will result in a nosed 105MM projectile conforming to NPI specifications. A chart (Fig. 3) summarizing the parameters is on page 27.

#### B. DISCUSSION OF OPERATING PARAMETERS

##### 1. Temperature, Thickness and Composition of Steel

The 3½" R.C.S. 1018 Steel in this study was required to be at normal forging temperature for the 105MM projectile, which is 1900° - 2000°F. In trial cuts at lower temperatures, the most notable effect was the influence of steel temperature on cutting speed. High quality cuts could be made at progressively higher speeds as bar temperature increased, with speeds at 2000°F. being as high as triple those with cold steel. Reliability of obtaining running starts also increased with increasing steel temperature. Meltdown also increased with bar temperature, with a given torch standoff distance.

Since all steel used in this study was 3½" R.C.S., type 1018 steel, there was no opportunity to evaluate the effect of varying steel thickness and composition. Such information is readily available in published material on oxygen cutting.

The tips available had .040", .060" and .080" cutting oxygen orifices and both straight and divergent orifices were obtained in each size. All six tips had a normal preheat arrangement, that is, six orifices arranged around the cutting orifice.

The largest (.080") tips were tried first and optimum settings were determined. The least pressure that allowed consistently good cutting was 80 psi measured at the regulator. This figure holds true for both the straight and divergent tips. Pressures lower than 80 psi would not yield reliable completion of cuts while pressures higher than 80 psi would not permit running starts and even gave occasionally poor standing starts. Cut quality above 90 psi was no better and was needlessly wasteful use of oxygen.

The .060" diameter tips gave consistently poor quality cuts and would not permit standing starts with certainty. This was the case with both divergent and straight orifices. It then followed that trials with .040" tips would be pointless. It was decided that the .080" divergent tip would be used for production of the contract quantity of mulchs.

## 2. Kerf Width and Tip Type

Two types of one piece cutting tips are in general use. One style has a cutting orifice that is drilled straight thru; the other has a divergent tapered bore. The latter style will produce a cutting oxygen jet that is narrower and straighter for a longer distance than the straight drilled type. This results in a narrower kerf, higher cutting speeds, and better cut surface quality for a given oxygen flow rate. Typical kerfs with divergent tips in  $3\frac{1}{2}$ " stock were  $1/8$ ". With straight orifice nozzles, kerfs were  $3/16$ " to  $1/4$ " with increased meltdown for a given standoff distance.

## 3. Cutting Oxygen Pressure and Tip Choice

Reference articles state that cutting oxygen pressure can be increased to a certain point beyond which increasing pressures will result in a loss rather than a gain in torch speed. This was found to be true for the tip sizes tried in this study. The optimum pressure for the tips finally chosen was arrived at by starting with the maximum pressure recommended by the manufacturer for cold cutting. When this setting would not produce reliable cutting without uncut corners or lost cuts, the pressure was reduced until quality cuts could be obtained with reliability. Trials to this point were made using a speed setting of about 22 inches/minute which is approximately twice the suggested speed for cutting cold steel with the same tip and pressures.



#### 4. Torch Travel Speeds

The torch tractor employed had a variable travel speed control which allowed speeds from 16 inches/minute to 33.7 inches/minute. All trials to determine best tip size and cutting oxygen pressures were begun at 22 inches/minute and increased in nine steps until the maximum of 33.7 inches/minute was reached or until difficulty was experienced in obtaining reliable cut quality. With the .080" tips, quality cuts could be obtained up to the maximum speed, but reliable starts required operating at 22 to 26 inches/minute. The required 100 mulch were cut using a speed of 22 inches/minute.

#### 5. Type of Starts

Torch travel can be initiated either in advance of the intended cut area with cutting oxygen turned on (running start) or the torch can be positioned at the starting edge of the cut with oxygen jet just touching the vertical face of the bar (standing start).

Running starts generally require lower travel speeds, less surface scale and more constant steel temperature to achieve reliable results. The principle advantage of a running start is that the time required to position the torch and start the oxygen flow is eliminated. However,

the oxygen usage will be higher because of the longer "on" time and the slower travel speed. Standing starts will allow higher travel speeds and will eliminate false starts.

The required 100 mults were cut with running starts with 96% reliability. The false starts were due to the steel temperature falling to the low edge of the tolerance range and possibly to slag fouling the cutting tip.

#### 6. Standoff Distance

Standoff, the distance between the torch tip and the surface of the steel, is normally very short for cutting steel at room temperature, often  $3/8$ " or less. In cutting steel at elevated temperature, the standoff must be increased to prevent excessive meltdown of the upper edges of the cut surfaces. Available literature on hot flame cutting suggests a standoff of not less than  $1\frac{1}{4}$ " to preclude slag spatter from fouling the tip. In this study, standoff distances from  $3/4$ " to 2" were tried. It was found that no ill effects occurred using  $3/4$ " standoff although the effect of increased standoff distance on minimized tip fouling cannot be argued. Distances greater than  $3/4$ " reduced reliability due to reduced effectiveness in penetration



of surface scale. Production of 100 mults was undertaken using a standoff distance of 3/4" without excessive meltdown and with increased start reliability.

#### 7. Torch Angle

In flame cutting steel at room temperature, the torch is held perpendicular to the steel surface. In hot cutting, available literature recommends inclining the torch about 2° in the direction of travel when using speeds in excess of 20 inches/minute. The effect is said to be most pronounced in high speed severance cutting where increased top speed and reliability result. The benefits are less pronounced at the moderate speeds used in quality cutting as in this study. Since mults were being cut from full length billets, the effect of twist in run of the mill bars precluded any study of torch angle with the existing torch and bar clamping setup.

#### C. CUT DIRECTION

Since the bar does not lie in a horizontal plane during cutting, the direction of torch travel will have an effect on flame cutting parameters. After initial tests run in the horizontal position to bracket rough speed and pressure settings, trial cuts were made in both uphill and downhill directions with the same settings. From observation of the

cut in progress and examination of the cut surfaces, it was immediately obvious that further work could be carried out in the downhill direction only. Subsequent tests run periodically during trials to establish other parameters gave similar results, as did trials using the finally chosen set of parameters. An uphill cut would invariably result in slag buildup in the kerf, leading to instability of the oxygen jet, with resulting poor mult end quality and low reliability. The 100 quantity was produced with the torch running downhill.

#### D. ELIMINATION OF SLAG

All of the trial cuts made left some amount of slag adhering to the bottom of the cut piece adjacent to the kerf. Under some conditions, slag also appeared on the top of the piece. The amount and location of the slag was a consideration in establishment of operating parameters. At the settings used in production of the 100 piece requirement, the slag quantity was near minimum.

Several methods of avoiding slag buildup were tried.

1. Since the slag is very fluid at cutting temperature, it had a tendency to run down the inclined bottom of the bar and solidify in droplets. An attempt to avoid this by cutting with the bar in a horizontal plane was undertaken. It was anticipated that the fluid slag would be blown clear by the cutting jet. The setup involved using a conventional

cutting machine setup on a flat table, using hot mult-length pieces taken from a 105MM production billet heater. Flame cutting parameters were the same as used for the production quantity, and the results were no different than cutting with the bar at 45°.

2. With the same horizontal cutting arrangement, an air jet was used in an attempt to blow the slag clear of the kerf. The setup consisted of a length of 1/8" pipe connected to a 90 psi air main directed horizontally along the kerf area on the bottom of the bar. The result was that slag was spread out thinly over a wider area. The air jet also disturbed the cutting oxygen jet and caused poor cut quality.
3. During the attempts to reduce or eliminate slag adherence, a question arose as to whether surface scale on the bar stock contributed to the slag problem. This was resolved in two ways. First, observation of the horizontal position cuts which were made with shot-blasted mults, demonstrated that the slag produced was the same as with uncleaned steel. To verify this, a short length of bar stock was shot-blasted and handled thru the flame cutting setup that was used for the rest of the study. Again, there was no discernable difference in the nature or quantity of slag produced. Flame cutting of shot-blasted steel also demonstrated a slight increase in reliability and cut quality.

4. An attempt was made to mask off the bottom of the bar in the kerf area with a copper plate having a 1/4" slot milled in it to correspond to the expected kerf location and shape. The plate was held tightly against the bottom of the bar by a steel bracket. (Fig. 2 on Page 26.)

Results of flame cutting with the copper plate in place showed that the slag had a tendency to solidify in the slot. Also, the molten slag has a great affinity for the hot steel surface and penetrated the clearance between the plate and the bar. The result was that the separated mult would cling to the copper plate. Once separated, there was still an objectionable amount of slag on the mult. It is apparent that this approach to the slag problem is impractical.

#### E. MULT END CONDITION

##### 1. Flame Cut Face Configuration

The flame cut face constitutes a plane surface, the upper edge (nearest the torch) and the lower edge of which are radiused slightly. The leading edge (the side first cut) is similarly radiused but on the edge of a shallow bevel. The last edge cut shows a slight raised edge in some cases but not enough to show any effect in the forging. The angle of the plane surface is controlled by the angle of the torch and the squareness of the track relative to the bar axis, both of which may be adjusted. Repeatability of a given angle is determined by play in the tractor/track



mechanism. Though no tabular data exists on this parameter, spot checks indicated a deviation of no more than  $1^{\circ}$  from a set angle.

## 2. Cut Surface Finish

The cut surface shows drag marks which take the form of serrations resembling those of sawed mults, but curved slightly. With the final parameters chosen, there are approximately 14-18 lines/inch. In good quality cuts, the marks are nearly indiscernable.

Tightly adhering, very thin scale is found on the cut surface and is similar to that found on the surface of steel which has been cut at room temperature.

## 3. Slag

The slag ejected from the kerf during flame cutting may contain one quarter molten steel and three quarters iron oxide. Both components of slag are very fluid at elevated temperatures and have a great affinity for heated steel. Unlike flame cutting of steel at room temperature where slag may be blown clear, with heated steel the slag will flow along the bottom edge of the kerf and solidify there upon cooling. The oxide component of this slag is extremely hard and brittle and can be chipped off. The molten steel, however, forms a lip that cannot be removed except by some mechanical means such as chiseling. The photos (Figs. 4-6) on pages 28-30 shows the flame cut end of a mult from which

the oxide component of the slag has been removed by shot-blasting. The remaining lip of steel is readily observed.

Regardless of the parameter values tried in this study, at no time could a cut be made without at least some slag remaining. The mult shown in the photo mentioned above was cut with the parameters finally chosen for completion of the 100 mult quantity, and exhibited a near minimum slag condition.

In order to obtain additional information on the subject of flame cut quality, contact was established with a representative of the flame cutting equipment manufacturer. A subsequent visit made by three members of the representative organization resulted in the rendering of the following opinions:

- a. The best possible results were being obtained with the equipment available. No cut surface quality improvement would be likely using other equipment, but a slight increase in speed with the same quality was possible using a different torch tip of a type not suited to the present torch.
- b. Adherence of some slag is inherent in the hot flame cutting process. Excessive slag adherence could be caused by cutting the bar at 45° angle. (As mentioned earlier, subsequent tests showed that cutting a bar in horizontal position yielded no difference in the slag condition.)
- c. High speed production cutting of billets such as in steel mills is usually done with water cooled equipment in which the torch moves in an arc rather than thru a horizontal



plane. A typical such machine would be the Linde CM-35 with a high flow, water-cooled torch using a two-piece tip. Such equipment would offer no improvement in the slag condition or cut surface quality but would rather yield a much higher cutting speed with some sacrifice in cut quality.

#### 4. Metallurgical Effects

An advantage claimed for flame cutting hot steel over cold steel is the relative freedom from metallurgical changes in the steel. This was found to be true in this study.

A 1/2" thick longitudinal section was taken from the center of a forging made from a mult flame-cut at both ends. A grid of 1/2" squares was laid out over the flat surface of this section and a Rockwell Hardness Test was performed in the center of each square. The resulting hardness pattern was compared to one taken in an identical manner from a normal production forging made from a sawed mult. The pattern fell within the normal tolerance range for hardness value and distribution. (See Fig. 7 on Page 31.)

The reverse side of the sample section was macroetched and the grain pattern was examined. No difference in grain flow could be found between this sample and the one taken from a forging produced under the same conditions but from a sawed mult.

## F. COST CONSIDERATIONS

### 1. Capital Costs

Exact figures for first cost of flame cutting equipment was not researched but it is known that cutting equipment such as used for this study plus proper tanks, piping, manifolds, etc. could be purchased for several thousand dollars. Not included is the material handling equipment necessary to transport the steel from heater to cutting equipment to forge.

The significant fact is that capital cost for hot flame cutting equipment is a fraction of first cost for other severing methods. For production cutting, water cooled equipment is recommended.

### 2. Variable Costs

A projection of costs can be made based on the experience in this study, involving cost of gasses and kerf loss cost. Scrap loss cost is also variable cost but cannot reliably be developed from this study. Using the process parameters chosen for producing the required 100 mulds, the costs are as follows:

Cost of Cutting Oxygen per cut	=	3.27¢
Cost of Preheat Gas per Cut	=	1.95¢
Cost of Kerf Loss	=	<u>7.03¢</u>
TOTAL COST	=	12.25¢

Related calculations are shown on page 32, Fig. 8.

Labor cost would vary depending on the particular setup but presumably one operator would be required.

#### IV. PROCESSING OF FLAME CUT MULTS

The contract required that 100 mults be sawed to one inch over normal mult length and then flame cut on one end to normal mult length while at normal forging temperature. Due to the ready availability of a billet heater capable of heating full mill lengths of steel, it was desirable to flame cut the mults one inch oversize and after cooling, saw to proper mult length. This was agreed to by Frankford Arsenal and the study was carried out in this manner.

The mults thus prepared were to be descaled and forged in two groups: Fifty (50) with the flame cut end up in the forging die and 50 with the flame cut end down. They were then to be inspected by the magnetic particle method, processed thru the nosing operation, and again inspected by the magnetic particle method. Visual inspections were included at each step. Results were to be recorded and documented in the final report.

The parameters finally chosen for production of the required 100 mults were as follows:

Cutting Tip: One piece divergent type, diameter of straight portion .080", six preheat orifices (Linde Oxyweld type 1514, size #80)

Cutting Oxygen Pressure: 80 psi (60 psi at the torch)

Acetylene Pressure: 7 psi

Torch Travel Speed: 22 inches per minute

Torch Standoff: 3/4" from cutting tip to steel surface

Type of Start: Running

Steel Temperature: 1950°F.  $\pm$  50°

Since it was not possible to completely eliminate the slag, it was decided to process thru nosing an initial quantity of mults with the slag remaining on the mult end. If no defects detrimental to production of acceptable 105MM shells were indicated by visual and magnetic particle inspection following the forge, rough turn and nose operations, the balance of the quantity would be processed in the same manner. Should any such indications be present, the overlapping scale and solidified steel would be removed before processing to more clearly show any other effects of hot flame cutting in the forging and nosed shell.

A. Initial Trials - Mults with Slag not Removed

The initial trial quantity consisted of twelve flame-cut pieces which are tabulated in Fig. 9 on page 33. The eleven pieces were flame cut one inch overlength and sawed to proper length. Five of these were forged with flame cut end up in the forging die and six were forged with the flame cut end down. One mult was flame-cut to proper length on both ends and forged. This piece was taken for metallurgical examination. The eleven pieces were examined visually and the lip formed by the molten steel and slag during flame cutting could be seen drawn out approximately one inch and impressed in the outside surface of all forgings. A subsequent inspection by the magnetic particle method confirmed the visual observation but did not uncover any further defects with the exception of external seams of the type normally found in the billet steel. These were evident in nine of the eleven pieces.



The piece flame cut at both ends was sectioned and the profile of the sectioned piece clearly showed the depth and extent of the lap depression. The sectioned piece was used to establish the hardness pattern and was etched to show the grain flow. Results were reported in III. E. 4 above.

The eleven pieces were rough-turned to establish the degree of cleanup that could be accomplished. A visual inspection revealed that all laps had been removed but four (Nos. 4, 5, 8 and 9) of the eleven pieces still had depressions where the laps had been. Inspection of these pieces by the magnetic particle method revealed a slag lap on one piece (No. 4) that had not been visible in the visual inspection. On six of the eleven pieces, external seams were still evident.

The eleven rough-turned pieces were then formed thru the nosing operation. Three of these were rejected after the cold draw operation due to the presence of severe external seams. The balance were carried thru the nosing operation intact. A visual inspection revealed evidence of a slag pit in the boattail area of piece #8 which was judged to be readily removeable in normal salvage operation. Piece #4, which showed a slag lap after rough turning, had a slight but salvageable surface defect near the open end.

These results indicate that a potentially high rate of salvage operations might be expected. Since these mults were processed with the minimum possible slag condition, any deviation from the parameters used would result in more slag and even less favorable results in terms of laps and pits.

The results from these few pieces are not statistically significant but the need is indicated for further study. Reliable data must be established on salvage requirements at various stages of manufacture of shells produced from hot flame-cut mults if use of this process is to be pursued.

The small quantity produced also precluded any experimental assessment of the effect of slag on forge die life. The opinions of the engineering personnel at NPI involved in the forging operation are that the hard and abrasive nature of the slag would be seriously detrimental to the life of the forging dies.

With the slag problem defined, it remained to isolate it by removing the slag and scale and processing the remaining mults. This served to eliminate the slag problem as a source of defects and permitted examination of the mults for any other effects of the hot flame cut process.

#### B. MULTS PROCESSED WITH SLAG REMOVED

The results of the initial trials indicated that the balance of the mults should be processed with the slag removed. This was done by first shotblasting the mults to remove the hard oxide component of the slag, after which a typical mult resembled that shown in the photograph on pages 28-30, Figs. 4-6.

The remaining lip of steel was removed by hand, using an air chisel. The mults were then processed thru the forging and nosing operations, with visual and magnetic particle inspection after each of the operations. No defect condition was revealed in the inspections, and no effect of the hot flame cutting process was evident in any of the nosed shells.

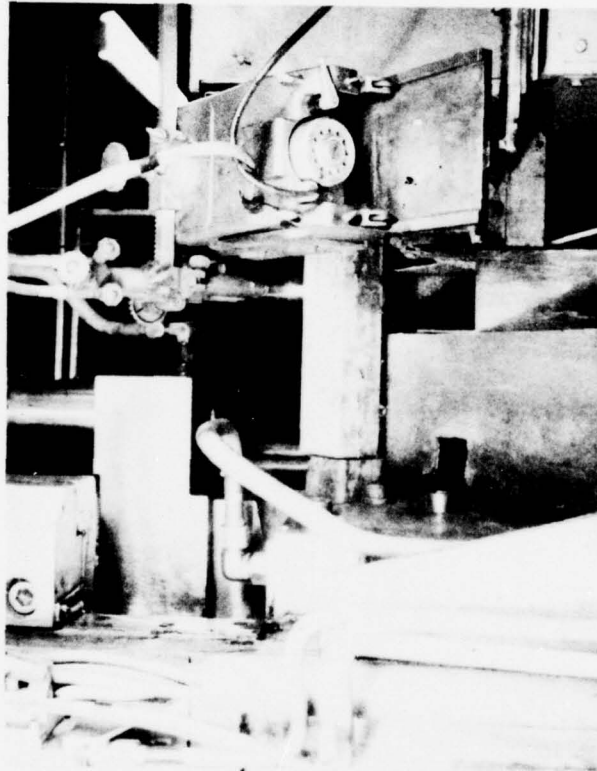
#### C. WEIGHT CONTROL

Mult weight was checked on the 89 pieces produced in the final lot. Since these were made in three groups on three different days, the averages were determined separately for each group. The data and results appear on page 33, Fig. 9. The ranges of weights in each group indicate acceptable weight control if the process was to be used as a salvage method. If used as an on-line production method, the weight control would fall outside the acceptable range used at NPI for sawed mults, which is plus or minus .2 pounds. In a salvage operation, such as salvaging billet ends from a hot shear operation, only one end would be flame cut. This would result in less weight variation than was experienced in this study wherein both ends were flame cut.

#### D. CONCLUSIONS

1. Flame cutting of 1018 steel at forging temperature can be performed at speeds greater than on room temperature steel.
2. Slag produced by the cutting process clings tenaciously to the heated steel at the kerf edge and precludes the reliable production of acceptable 105MM forgings unless the slag is mechanically removed prior to the forging operation.
3. Except for the slag problem, quality of flame cut mulds produced using the parameters established in this study is adequate for production of 105MM forgings using the Hot Cup-Cold Draw Process.
4. Capital cost of flame cutting equipment is low compared to other billet severing equipment. Variable costs, including kerf loss and cost of gasses, are relatively high.





TORCH

CUTTING MACHINE  
TRACTOR

BILLET HEATER

CHUTE FOR MULT DELIVERY

BILLET IN POSITION  
FOR CUTTING

BILLET STOCK  
CLAMPED IN PLACE  
TO SERVE AS STOP

FIGURE 1. HOT FLAME CUTTING EQUIPMENT SETUP.

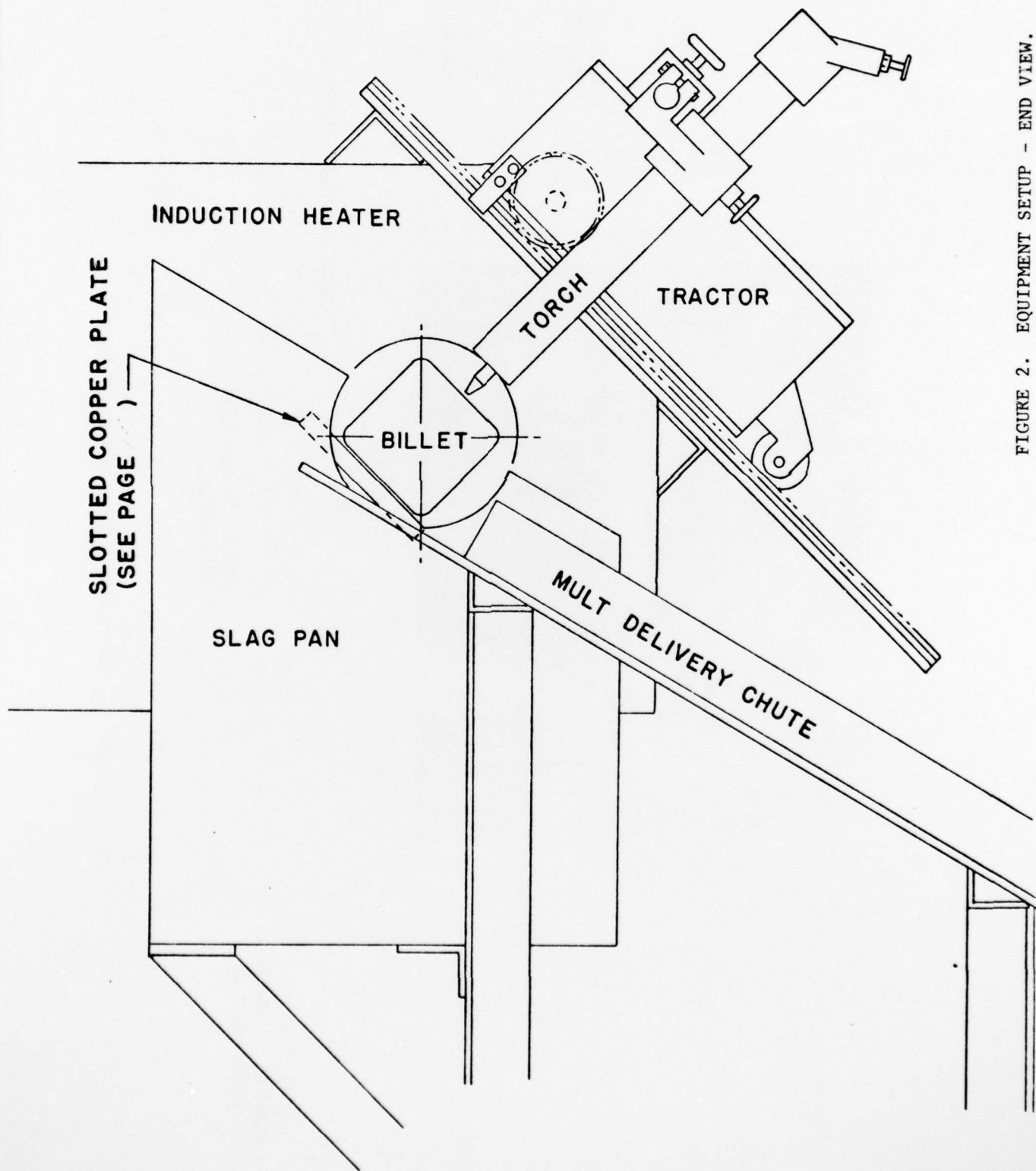


FIGURE 2. EQUIPMENT SETUP - END VIEW.

	TIP TYPE	TIP SIZE	BILLET TEMPERATURE	STANDOFF DISTANCE	CUTTING OXYGEN PRESSURE
KERF SIZE	Divergent type Yields narrower kerf than straight type	Minimal	Minimal	Melt down affects kerf width at top of cut	Minimal assuming good quality and reliability
STARTS (RUNNING OR STANDING)	None	Larger tips promote reliability of running starts	Starts are more reliable as temperature increases	Starts become more reliable as standoff decreases	Excessive pressure reduces start reliability
CUT QUALITY	Divergent tips give slightly better quality	Larger tips give better quality	Melt down increases with temperature	Greater standoff gives less melt down	Excessive pressure reduces cut quality
TORCH TRAVEL SPEED	Divergent tips permit higher speeds	Larger tips permit higher speeds	Higher temperatures permit higher speeds	Shorter standoff distances allow slightly higher speeds	Too low pressure causes lost cuts
CUT CONTINUITY	None	Too small tips reduces reliability	Lower temper- atures reduce max. speeds to allow continuity	Excessive standoff reduces reliability	Too low pressure reduces reliability

FIGURE 3. PARAMETER RELATIONSHIPS.



FIGURE 4. HOT FLAME CUT SURFACE OF SHOT BLASTED MULT.  
SLIGHT MELTDOWN CAN BE SEEN AT TOP EDGE.



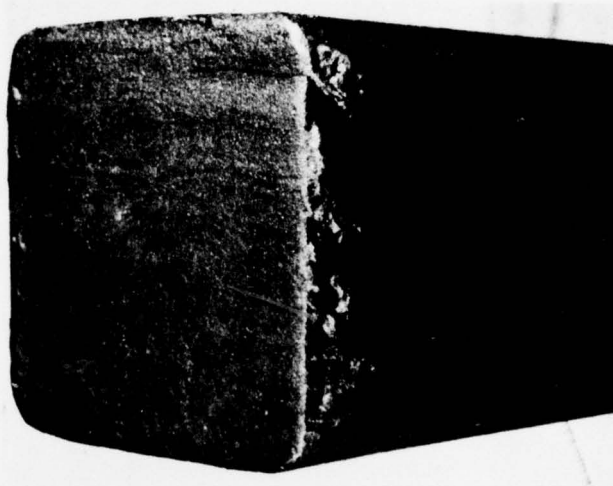


FIGURE 5. HOT FLAME CUT END OF SHOT BLASTED MULT. MULT IS INCLINED TO SHOW REMAINING LIP AFTER SHOT BLASTING.

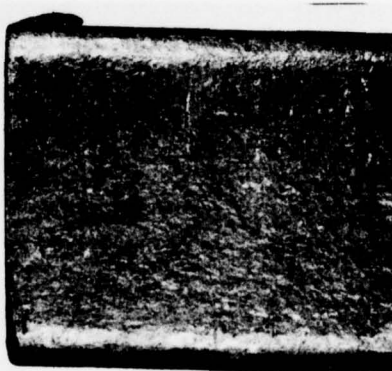
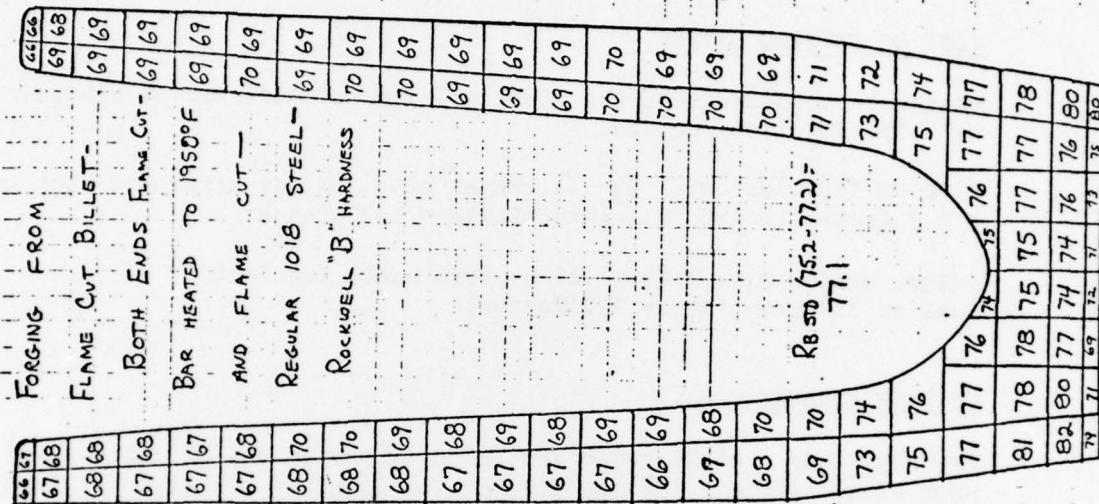


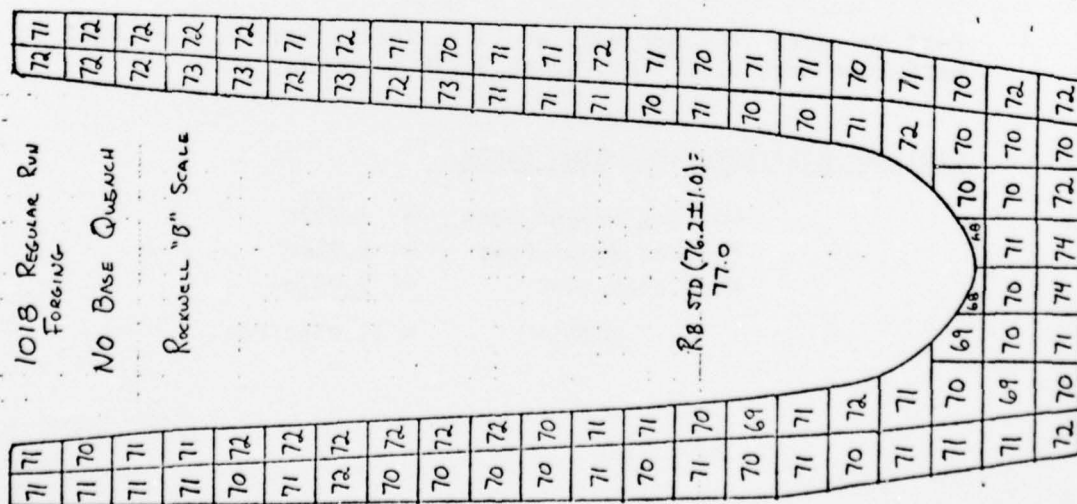
FIGURE 6. HOT FLAME CUT END OF SHOT BLASTED MULT. SIDE  
VIEW SHOWING LIP.

10-6-75



M.R.

3-30-76



M.R.

FIGURE 7. HARDNESS PATTERNS

FIGURE 8. VARIABLE COSTS (EXCLUDING LABOR)

COST OF CUTTING OXYGEN

Oxygen is supplied thru the .080" orifice at 315 cubic feet/hour, or 5.25 cubic feet/minute.

Time of flow per cut:  $3\frac{1}{2}$ " of travel plus 20% for start and stop  
= 4.2 inches/cut at 22 inches/minute = .19 minute.

Oxygen usage/cut =  $5.25 \times .19 = .9975$  cubic feet/cut  
Cost at 3.28¢/cu. ft. = 3.272¢/cut.

COST OF PREHEAT GAS

Preheat flame uses 20 cubic feet/hour of oxygen and 20 cubic feet/hour of acetylene. Cutting time of .19 minute = 40% of total time.  
Time of preheat per cut = .19 minute/.4 = .475 minute/cut.

$.475 \times \frac{20}{60} \times 3.28\text{¢/cu.ft.} = .519\text{¢/cut}$  for oxygen

$.475 \times \frac{20}{60} \times 9.05\text{¢/cu.ft.} = \underline{1.433\text{¢/cut}}$  for acetylene

Total preheat cost/cut = 1.952¢/cut

KERF LOSS COST

Kerf averaged 1/8" per cut, at 40.92 lb/ft, kerf loss = .4262 lb/cut.  
Kerf loss cost with steel at 16.5¢/lb = 7.032¢.

VARIABLE COST/CUT, EXCLUDING LABOR

Cutting Oxygen Cost	=	3.272¢
Preheat Flame Cost	=	1.952¢
Kerf Loss Cost	=	<u>7.032¢</u>
TOTAL	=	12.256¢/cut



FIGURE 9. INSPECTION RESULTS

MULT NO.	POSITION IN DIE	RESULTS AFTER:		
		FORGING	ROUGH TURNING	NOSING
1	UP	SEAM	SEAM	SEAMS-Rejected after draw
2	"	OK	SEAM	OK
3	"	SEAM		OK
4	"	SEAM	SLAG LAPS	OK *
5	"	SEAM	SLAG PITS	OK
6	DOWN	SEAM	SEAM	SEAM
7	"	SEAM	OK	Rejected after draw
8	"	OK	SLAG PITS	SLAG PIT-salvageable
9	"	SEAM	SLAG PITS	Rejected after draw
10	"	SEAM	SEAM	OK
11	"	SEAM	SEAM	OK
12	BOTH ENDS FLAME CUT - USED FOR METALLURGICAL EXAMINATION.			

	<u>WEIGHT AVERAGE</u>	<u>RANGE</u>
13 thru 45	31.185 lb.	.68
46 thru 82	32.048	.35
83 thru 100	32.083	.57

\*Salvageable  
Surface Defect

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